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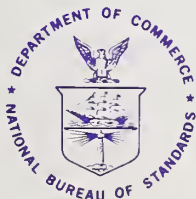
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SCIENCE & TECHNOLOGY:



THE LX39 LATENT FINGERPRINT MATCHER



NBS Special Publication 500-36
U.S. DEPARTMENT OF COMMERCE
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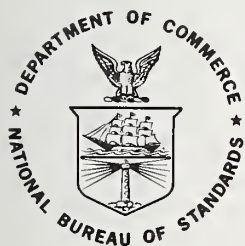
COMPUTER SCIENCE & TECHNOLOGY: The LX39 Latent Fingerprint Matcher

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The LX39 Latent Fingerprint Matcher

J.H. Wegstein and J.F. Rafferty

A procedure is described for automatically determining if a latent scene-of-crime fingerprint matches an inked, rolled file fingerprint. The procedure uses the x and y coordinates and the individual directions of the minutiae (ridge endings and bifurcations). The identity of the latent print with a print on file is indicated by a high score resulting from computations based on differences in angle and coordinate values of minutiae that are found in going from one of the fingerprints to the other.

Key words: Automated-fingerprint-
identification, pattern
recognition

1. Introduction

An average rolled fingerprint impression exhibits about eighty ridge endings and forks or bifurcations in its ridge pattern. By comparing the data representing these minutiae, a computer can determine whether or not two fingerprint impressions came from the same finger. Figure 1 shows how the x and y coordinates and the direction θ are defined for a minutia. If the areas marked A are ridges then the minutia is a ridge ending, but if the areas marked B are ridges the pattern is a bifurcation. Since a ridge ending in one print may appear as a bifurcation in another print from the same finger, no distinction is made between ridge endings and bifurcations in recording data.

A portion of a fingerprint along with a plot of the corresponding minutiae are shown in Figure 2. The minutiae data are read automatically from the rolled impressions on fingerprint cards and in addition, the reader also produces ridge direction data at equally spaced grid-points over the entire print. In a fully automated identification system, this ridge-direction data is utilized in finding the core or "center" of a print as well as the angle through which the print should be rotated.¹ This registration information is used to translate and rotate the minutia data into a standard position. The ridge-direction data in the neighborhood of each minutia is also used to make slight corrections to the angle θ of that minutia. Those registered minutiae within a certain distance of the center are then sorted into a descending order on y and this data may then be placed in a file or used to search against minutia data in a previously established file.

While the high speed M40² and M41 matchers can compare data and identify rolled fingerprints, a different technique is used for

identifying latent fingerprints found at the scene of a crime. Latent prints often produce only a portion of a fingerprint with correspondingly fewer minutiae than can be read from rolled fingerprints. Some typical latent fingerprints along with their mates from fingerprint cards are shown in Figure 3.

Because of their poor quality, latent fingerprint minutiae are read by a fingerprint expert using a semi-automated reader.³ The semi-automatically read minutiae data from latent prints are then compared with the automatically read data from rolled prints by a special matcher that is slower and more elaborate than the high-speed rolled print matchers. It is often impossible to tell which of the ten fingers produced a latent print. Consequently, the search process is further delayed because the latent search print data must be compared with the data from several of the rolled prints on each file card.

The previously reported M40 matcher can be characterized as a two-stage matcher whose software version requires about 20ms to match a pair of prints and whose hardwired version matches a pair of prints in less than a millisecond. On the other hand, the LX39 latent print matcher described here is a seven stage matcher requiring about 100ms to match a pair of prints in its software version. This matcher includes a number of parameters that limit its time requirements at a slight risk of missing a match.

2. Selecting Minutiae - Stage I

Figure 4 shows a latent search print and its mating file print along with a ten-times enlarged plot of its manually-read minutiae  superimposed on a portion of the machine-read minutiae  from the inked file print. Note that there are the usual false and missing minutiae.

In stage I, a box of parameter-determined size is centered on each of the search minutia and the enclosed file minutiae are tabulated in an array, JT, as shown in Table I. The angle of each of these tabulated file minutia must not differ from the angle of the corresponding search minutia by more than a parameter-determined limit (angles are measured in degrees and distance is measured in units of one-tenth millimeter).

Search
Min.

File Minutiae

I	LM	LI	JT1	JT2	JT3	JT4	JT5	JT6
1	3	3	8	12	15	0	0	0
2	6	1	5	6	7	9	11	16
3	2	4	13	14	0	0	0	0
4	4	6	11	17	18	19	0	0
5	6	7	9	11	16	17	18	19
6	4	2	13	26	27	29	0	0
7	4	5	26	27	29	31	0	0
8	6	8	24	26	27	30	32	33
9	0	10	0	0	0	0	0	0
10	6	0	26	27	30	32	33	34

Table 1.

For example, the box around search minutia 2 in Figure 4 encloses file minutiae 5,6,7,9,11,16 as indicated above. A parameter limits the number of file minutiae entered in the JT table to the first six found in the box and ignores 18 and 20. Column LM indicates the number of entries in each row. Column LI orders the rows in ascending order according to column LM. That is, the first value, LI=3, indicates that for I=3, LM₃=2 is the lowest value in column LM (zero excluded). The next value, LI=1 indicates that LM₁=3 is next lowest, and so on.

3. Trial Pair Selections - Stage II

The matcher next seeks pairs of search minutiae that coincide with pairs of file minutiae. The method of computing the score for a pair-fit is shown in Figure 5. DG,DH,DI, and DJ must each be less than an appropriate parameter. Then a large score, MS, indicates that the two pairs of minutiae fit each other well.

Following the order indicated by column LI in Table 1, search minutia IA=3 is first placed on file minutia JA=13. The matcher then tries to place search minutia IB=1, being the next item in column LI, on file minutia JB=8 or 12 or 15. Failing this, it will try to put minutia IB=4 on JB=11. After a very few of these failures, as determined by a parameter, the matcher will return and place search minutia IA=3 on file minutia JA=14 followed by placing IB=1 on 8, 12, and 15 where the first fit occurs. The fits are recorded in Table 2. This procedure continues, but the table length is limited by the trial terminating parameters.

M	MIA	MJA	MIB	MJB
1	3	14	1	15
2	3	14	4	19
3	6	26	8	27
4	7	26	10	33
5	7	27	8	30
6	7	27	10	32
7	2	7	5	9
8	8	24	10	30
9	8	27	10	33

Table 2.

Search minutia MIA=3 sitting on file minutia MJA=14 agrees with search minutia MIB=1 sitting on file minutia MJB=15 as can be seen in Figure 4. 3 on 14 also would agree with 4 on 19. Table 2 indicates that 8 might sit on 24, 27, or 30 and this inconsistency is resolved by further computation.

4. Pair Ordering - Stage III

All of the pairs in Table 2 are arranged in descending order according to the number of times, NJJ, that a pair occurs. Duplicates are eliminated. Each pair now appears as NIA-NJA along with its NJJ in Table 3.

		NQ																	
N ↓	NIA	NJA	NJJ	JS	M→	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	•	3	14	2	291	-1	-1	16	-1	19	26	-1	22	-1	-1	-1	-1	-1	-1
2	•	8	27	2	297	-1	-1	13	-1	28	-1	11	19	-1	-1	-1	-1	-1	-1
3	•	10	33	2	374	16	13	-1	-1	23	14	18	18	-1	-1	-1	-1	-1	-1
4		7	27	2	0	-1	-1	-1	-1	-1	-1	-1	-1	15	20	-1	-1	-1	-1
5	•	1	15	1	290	19	28	23	-1	-1	-1	21	25	0	0	0	0	0	0
6		4	19	1	229	26	-1	14	-1	-1	-1	-1	16	0	0	0	0	0	0
7		6	26	1		-1	11	18	-1	21	-1	-1	-1	0	0	0	0	0	0
8	•	7	26	1		22	19	18	-1	25	16	-1	-1	0	0	0	0	0	0
9		8	30	1		-1	-1	-1	15	0	0	0	0	-1	-1	0	0	0	0
10		10	32	1		-1	-1	-1	20	0	0	0	0	-1	-1	0	0	0	0
11		2	7	1		-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
12		5	9	1		-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
13		8	24	1		-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
14		10	30	1		-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0

Table 3.

The number of entries in Table 3 is limited by parameter to 30 thereby setting a limit on the computation time required.

In these tables, the correct mating minutiae are marked with dots to follow their behavior in the course of the matching process. It has been found in experimental searches that the true mating minutiae tend to float or rise to the top of Table 3. In actual practice the NJJ values are usually higher than those in the example shown here.

5. Verification of Pairs - Stage IV

Each of the first six pairs of minutiae in Table 3 that has a $NJJ > 1$ is compared with the rest of the entries in the table using the procedure described in Figure 5. The resulting MS score is entered as $NQ_{m,n}$ and $NQ_{n,m}$ in the array shown in Table 3. No computation is allowed if the NIA's or NJA's are the same. The -1's indicate that the computation failed to produce a match or that no computation is allowed. Zeros indicate that no computation was made.

From the NQ array it may be seen that pair 3 on 14 produces an MS score of 16 when tested with pair 10 on 33. A score of 19 occurs with pair 1 on 15 and so on. It can be seen from Table 3 that the true mating minutiae tend to produce the most scores along the appropriate rows of the NQ array.

6. The IS Score

The LX39 matcher computes two scores, IS and RS. Either or preferably both of these scores can be used in a latent print search. The IS score is obtained by examining each of the first six rows in the NQ array except for those rows where $NJJ \leq 1$. Each row is scanned from left to right. Whenever a positive number is encountered, all of the other positive numbers in that column are added together. The total of these sums, JS, is the score for that row. For example, in row one, 16 produces a sum of $13 + 23 + 14 + 18 + 18 = 86$; 19 produces a sum of 97; 26 produces 30; and 22 produces 78. Then $JS = 86 + 97 + 30 + 78 = 291$. The JS scores for the different rows are shown in Table 3. The highest of these JS scores, $IS = 374$ is one of the final scores for the fingerprint match.

7. Relocation of Search Print Center Point - Stage V

The pairs of mating minutiae named by the matrix row that produced the IS score are used to locate a new center point for the search minutiae data. In Table 3, the third row names pairs 1, 2, 5, 6, 7, 8.

To develop the formulas for this procedure it must be noted that prior to being placed in file, the file data were registered so that the core or center point of the finger print was at a standard location cx, cy . Therefore this point can be located relative to any file

minutia F with datum X_F, Y_F, θ_F . In Figure 6, the point c_x, c_y can be located relative to F using angle ϕ and distance R where $\phi = \theta_F - \theta_A$.

If a search minutia S is supposed to lie on the file minutia F then a search print center x_c, y_c can be located relative to S using its datum, X_S, Y_S, θ_S along with R and ϕ as shown in Figure 6. Accordingly, each of the mating minutiae pairs named for getting IS is used to compute a point x_c, y_c . The resulting x_c, y_c points are in a small cluster and the center of this cluster (x_x, y_y) , is taken as the new center point for the search minutiae. The angle, $\mathcal{N}$, through which the search minutiae must be rotated is the mean value of $\Delta\theta$ where $\Delta\theta = \theta_F - \theta_S$ corresponding to each of the mating pairs of minutiae that were selected earlier.

8. Re-registration of Search Minutiae - Stage VI

The set of all search minutiae which had been centered at the standard location c_x, c_y are translated so that the point x_x, y_y is now at c_x, c_y and at the same time, the set is rotated through the angle $\mathcal{N}$.

9. The RS Score - Stage VII

Once again considering the search minutiae to be superimposed on the file minutiae, a small parameter-determined box is centered on each search minutia. Any file minutia falling in this box with an angle that differs by only a small amount, determined by a parameter, from the search minutia angle is paired with the search minutia for determining the final matching score: RS. In the example used earlier, six mating pairs of minutiae emerge as shown in Figure 7.

M	Search	File
1	1	15
2	2	16
3	3	14
4	7	26
5	8	27
6	10	33

Table 4.

Note that one pair, 2 on 16, had not been used in previous stages of the matching process. The minutiae data of each of these pairs is used to compute a score, FRS, where:

$$FRS = \text{constant} - |X_S - X_F| - |Y_S - Y_F| - |\theta_S - \theta_F|$$

The final score, RS, equals the summation of these FRS scores.

10. Testing the Matcher

In order to test the performance of the LX39 matcher, 50 latent fingerprints including the four shown in Figures 3 and 4 were read with a semi-automated reader by latent fingerprint experts. These prints were then searched against a file of fifty fingerprint cards where each card was known to contain a print corresponding to one of the latent prints. (For convenience, a search print was given the same identification number as the file card containing its mating print.) The minutiae data from eight fingers of each card (little fingers excluded) were read by a fully automatic minutiae reader.⁴

Because it was originally impossible to tell which of the ten fingers produced the latent prints, each latent print was compared with all eight fingerprints from each card in the file. That is, the LX39 matcher compared each search print with 400 file prints. For each search print, the highest and second highest RS scores were determined along with their appropriate card and finger identifications. The highest and next highest IS scores with their card and finger identifications were also determined. When each search print was being compared with the eight prints of a given file card, the sum of the eight RS scores, RST, was also computed and the sum of the IS scores, IST, was also computed. For each file search, the highest RST score with its card identification and the highest IST score with its card identification were then determined. The resulting card numbers and scores are tabulated on page 15. In this table, the matcher has produced six file card numbers for each search print. The search print is considered to be identified if any of these six numbers agrees with the number of the search print.

11. Experimental Results

The "hits" are marked by dots on page 15 and the 42 "identified" latents are marked with an X. Latent print number 12 (finger 9) shown in Figure 4 failed to achieve any of the highest RS scores, but it did get the highest IS score (374) as well as the highest IST score (488). Latents 23 and 54 shown in Figure 3 were identified (see page 15). Latent 20 failed to be identified in spite of the fact that matching minutiae from its true file mate were at the top of the NQ array during stage III of that comparison.

In this test there were five cases where the right card was hit by the wrong finger. In three of these cases the right finger was also hit by an even higher score as is shown in Table 5.

Case	Latent Finger Type	File Finger Type	Score
1	4-3 U	4-4 U	IS=1418, RS=133
2	22-2 W	22-3 W	IS=484
3	38-3 U	38-3 U	RS=208, IS=1538
	38-3 U	38-4 W	RS=143
4	70-2 W	70-2 W	RS=157, IS=850
	70-2 W	70-9 W	RS=103
5	88-8 W	88-8 W	RS=231, IS=1588
	88-8 W	88-6 W	RS=168, IS=1458

Table 5

In another experiment with the same prints where the minutiae data were read with a different semi-automated reader, there were seven of these cases of correct cards hit with wrong fingers. In these cases the contributing minutiae were examined on the fingerprints and were indeed found to match each other. This suggests that there is a tendency for two or more fingers from the same person to have similar minutiae patterns. It would be interesting to compare minutiae patterns from the right hand with reflected patterns from the left hand where the ridge patterns are already known to often be similar. This experiment also suggests that latent examiners seeking to verify a hit should compare the latent print with other prints from the same card when a file print that was "hit" by a search fails to agree with the latent print.

12. Conclusion

The LX39 fingerprint matcher appears to be capable of making latent fingerprint identifications in a practical latent search system. The software version of the matcher requires about 100 ms to compare a pair of prints, and consequently a large file might require a hardware version of this matcher. The small number of prints tested here are not sufficient to predict the performance on a large file or to indicate how many retrieved cards for each search print must be examined by an expert to confirm identification.

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13. References

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2. Wegstein, J.H., The M40 Fingerprint Matcher, National Bureau of Standards Technical Note 878, U.S. Government Printing Office, Washington, D.C., 1972
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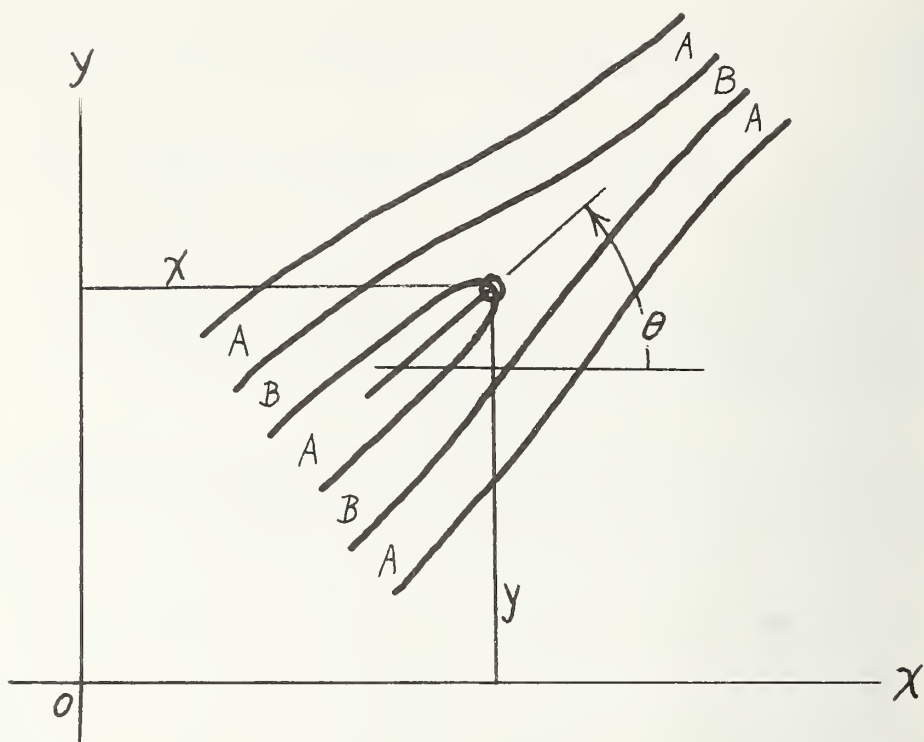


Figure 1. Definition of Minutia Data

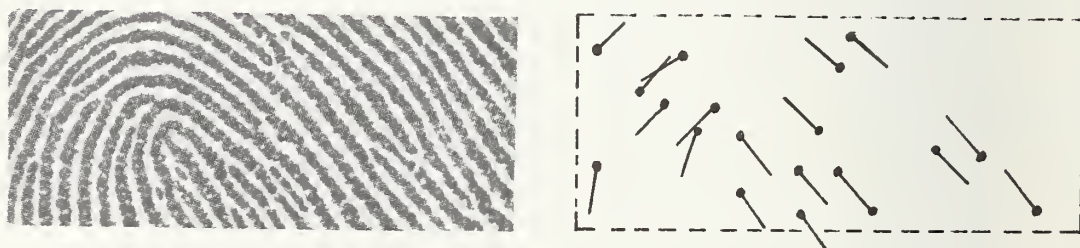
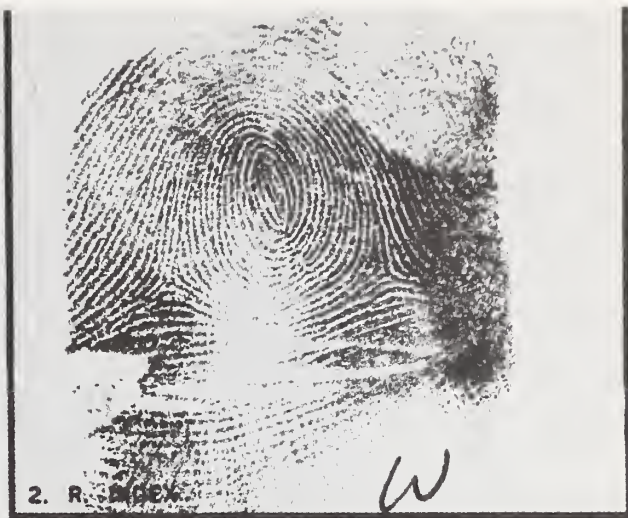


Figure 2. A Portion of a Fingerprint with a Plot of Corresponding Minutiae



20-2



23-7



54-6



Figure 3. Latent search fingerprints (left) with mating rolled file fingerprints (right).

12-9

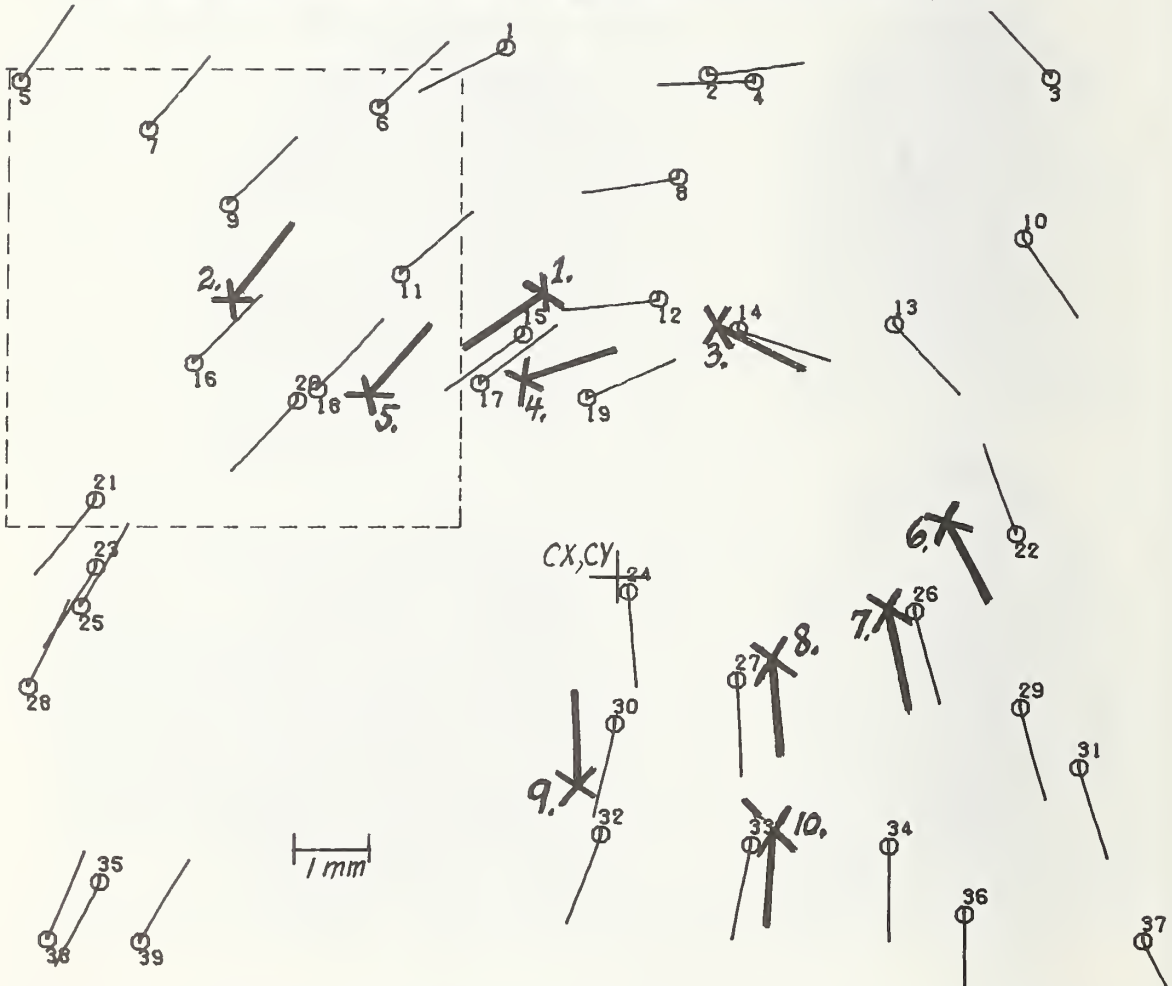


Figure 4. (Above), Latent search fingerprint with its mating file print (x2). (Below), a portion of file minutiae —○ read automatically with superimposed latent minutiae —X read manually on a semi-automated reader (x10).

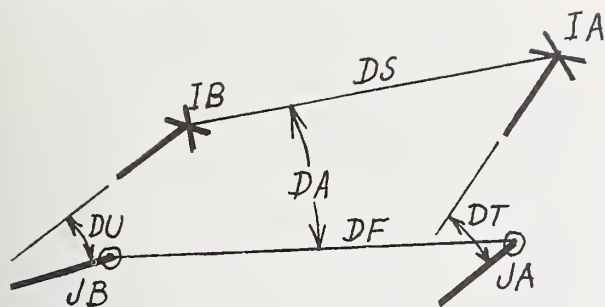


Figure 5. Matching Pairs of Minutiae

$$DG = |DT - DU|$$

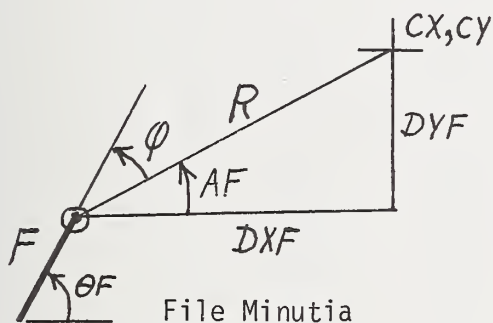
$$DH = |DS - DF|$$

$$DI = |DU - DA| \quad DJ = |DT - DA|$$

$$DZ = \text{Lesser of } DI \text{ and } DJ$$

$$DW = \text{Greater of } DI \text{ and } DJ$$

$$\text{Score: } MS = \text{Constant} - DH - DZ - DW$$



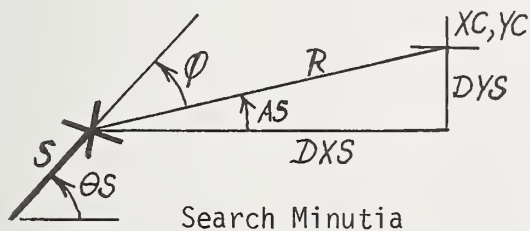
$$DXF = CX - XF$$

$$DYF = CY - YF$$

$$R = \sqrt{DXF^2 + DYF^2}$$

$$AF = \arctan \frac{DYF}{DXF}$$

$$\phi = \theta_F - AF$$



$$AS = \theta_S - \phi$$

$$DXS = R \cos AS$$

$$DYS = R \sin AS$$

$$XC = XS + DXS$$

$$YC = YS + DYS$$

$$D\theta = \theta_F - \theta_S$$

Figure 6. Locating a New Search Minutiae Center

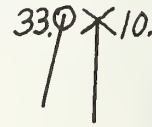
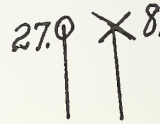
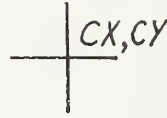
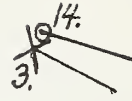
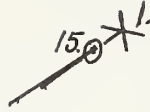
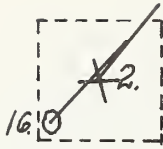


Figure 7. Final Minutiae Pairing

Search Print	1 St Card RS	2 nd Card RS	1 St Card RST	1 St Card IS	2 nd Card IS	1 St Card IST
X 1	1• 250	78 181	46 706	1•4324	40 770	1•4672
X 4	78 150	4• 133	46 483	4•1418	78 936	90 1884
X 6	62 118	60 117	12 477	6• 642	22 500	27 930
X 8	8• 161	25 143	46 588	8•1350	40 610	46 2178
X 12	73 109	15 96	22 342	12• 374	15 232	12• 488
X 14	14• 318	24 237	14• 893	14•1528	64 1142	14•2884
X 15	63 190	90 189	62 927	90 1554	15•1172	90 3138
X 17	17• 229	90 221	90 1049	21 2244	76 1320	21 3298
19	14 92	46 87	43 210	14 210	46 162	46 326
20	8 131	88 115	83 425	15 436	8 408	15 784
X 21	21• 243	93 178	88 804	21•2972	42 1072	21•4550
X 22	46 139	71 129	46 572	46 584	22• 484	46 1228
X 23	23• 136	83 135	90 545	23• 400	90 288	90 1000
X 24	64 153	24• 136	22 460	64 510	38 458	88 1108
X 25	25• 456	19 199	25• 796	25•7624	54 1334	25•7936
27	43 168	83 165	43 780	62 968	25 784	15 1608
28	12 239	93 232	93 835	93 1274	12 988	42 2078
X 30	57 204	15 193	15 706	30•1832	57 836	30•1964
32	27 192	76 176	43 614	17 610	57 586	83 1044
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X 38	38• 208	38• 143	38• 548	38•1538	60 894	38•1998
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X 54	15 115	54• 90	54• 225	54• 838	78 170	54• 934
55	63 155	12 148	40 658	63 1356	19 742	63 1562
X 57	57• 164	88 147	46 638	57•1530	88 952	90 2048
X 60	88 179	60• 156	88 684	62 682	88 682	88 2494
X 62	62• 185	90 146	62• 834	62•2578	90 1172	62•4078
X 63	63• 172	23 124	88 354	63•1046	83 536	63•1046
X 64	64• 162	94 148	27 478	42 1336	69 1126	69 1840
X 69	69• 245	34 175	34 586	69•1060	14 754	69•1424
X 70	70• 157	70• 103	28 350	70• 850	12 414	70• 938
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